7-2011

The impact of ractopamine hydrochloride on growth and metabolism, with special consideration of its role on nitrogen balance and water utilization in pork production

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Abstract

Two experiments were conducted to determine if ractopamine hydrochloride (RAC) could improve nutrient utilization and decrease water utilization, thus reducing the environmental footprint of hog operations. The tissue accretion experiment used comparative slaughter involving 120 barrows (95 ± 3 kg of BW), including 12 assigned to an initial slaughter group; the remaining pigs were slaughtered at 108 or 120 kg. Growth performance and nutrient retention were determined. The 15-d metabolism experiment consisted of 54 pigs (95 ± 3 kg of BW). Growth performance, feed and water intake, and urine and fecal output were measured. The metabolism experiment used 9 dietary treatments arranged as a 3 × 3 factorial: 3 quantities of RAC (0, 5, and 10 mg/kg) and 3 standardized ileal digestible-Lys:DE ratios (1.73, 2.14, and 2.63 g/Mcal of DE). The tissue accretion study was designed as a 3 × 3 × 2 factorial arrangement of treatments using the same 9 dietary treatments to include slaughter BW (108 and 120 kg of BW) as an additional factor. In the tissue accretion experiment, RAC had no effect on ADG, ADFI, or G:F ($P > 0.10$). With increased Lys, G:F improved ($P = 0.029$), but not ADG or ADFI ($P > 0.10$). Protein deposition rates increased numerically ($P = 0.11$); water deposition rates increased ($P = 0.050$), whereas lipid deposition tended to decrease with RAC inclusion ($P = 0.055$). With greater RAC and Lys, the pigs had improved ADG ($P = 0.002$) and G:F ($P < 0.001$) in the metabolism experiment. Daily water intake ($P = 0.017$.) and water output ($P = 0.033$) decreased with RAC inclusion. Lysine inclusion did not alter the water balance ($P > 0.10$). Urinary N excretion ($P < 0.001$), total N excretion ($P = 0.003$), and the urine N:fecal N ratio ($P < 0.001$) decreased with the addition of RAC; fecal N ($P = 0.008$) increased with RAC inclusion. Retention of N improved with addition of RAC to the diet ($P = 0.003$). With greater dietary Lys, fecal N was reduced ($P < 0.001$). The pigs fed the 2.14 g of Lys/Mcal tended to have the least urinary N ($P = 0.069$) and total N excretion ($P = 0.086$) and to have the greatest N retention ($P = 0.086$) and urinary N:fecal N ratio ($P = 0.009$). A RAC × Lys interaction was observed for N digestibility ($P = 0.001$), excretion ($P = 0.001$), and retention ($P = 0.002$) and for fecal ($P = 0.001$) and urinary N ($P = 0.036$). By improving N and water utilization in finishing pigs, RAC-containing diets supplemented with sufficient Lys can reduce N excretion into the environment from swine facilities.

Keywords

environment, nitrogen balance, ractopamine, swine, water

Disciplines

Agriculture | Animal Experimentation and Research | Animal Sciences | Biochemical Phenomena, Metabolism, and Nutrition | Environmental Sciences

Comments

This article is published as Ross, K. A., A. D. Beaulieu, J. Merrill, G. Vessie, and J. F. Patience. "The impact of ractopamine hydrochloride on growth and metabolism, with special consideration of its role on nitrogen balance and water utilization in pork production." *Journal of animal science* 89, no. 7 (2011): 2243-2256. doi: 10.2527/jas.2010-3117.

The impact of ractopamine hydrochloride on growth and metabolism, with special consideration of its role on nitrogen balance and water utilization in pork production[1]

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ABSTRACT: Two experiments were conducted to determine if ractopamine hydrochloride (RAC) could improve nutrient utilization and decrease water utilization, thus reducing the environmental footprint of hog operations. The tissue accretion experiment used comparative slaughter involving 120 barrows (95 ± 3 kg of BW), including 12 assigned to an initial slaughter group; the remaining pigs were slaughtered at 108 or 120 kg. Growth performance and nutrient retention were determined. The 15-d metabolism experiment consisted of 54 pigs (95 ± 3 kg of BW). Growth performance, feed and water intake, and urine and fecal output were measured. The metabolism experiment used 9 dietary treatments arranged as a 3 × 3 factorial: 3 quantities of RAC (0, 5, and 10 mg/kg) and 3 standardized ileal digestible-Lys:DE ratios (1.73, 2.14, and 2.63 g/Mcal of DE). The tissue accretion study was designed as a 3 × 3 × 2 factorial arrangement of treatments using the same 9 dietary treatments to include slaughter BW (108 and 120 kg of BW) as an additional factor. In the tissue accretion experiment, RAC had no effect on ADG, ADFI, or G:F ($P > 0.10$). With increased Lys, G:F improved ($P = 0.029$), but not ADG or ADFI ($P > 0.10$). Protein deposition rates increased numerically ($P = 0.11$); water deposition rates increased ($P = 0.050$), whereas lipid deposition tended to decrease with RAC inclusion ($P = 0.055$). With greater RAC and Lys, the pigs had improved ADG ($P = 0.002$) and G:F ($P < 0.001$) in the metabolism experiment. Daily water intake ($P = 0.017$.) and water output ($P = 0.033$) decreased with RAC inclusion. Lysine inclusion did not alter the water balance ($P > 0.10$). Urinary N excretion ($P < 0.001$), total N excretion ($P = 0.003$), and the urine N:fecal N ratio ($P < 0.001$) decreased with the addition of RAC; fecal N ($P = 0.008$) increased with RAC inclusion. Retention of N improved with addition of RAC to the diet ($P = 0.003$). With greater dietary Lys, fecal N was reduced ($P < 0.001$). The pigs fed the 2.14 g of Lys/Mcal tended to have the least urinary N ($P = 0.069$) and total N excretion ($P = 0.086$) and to have the greatest N retention ($P = 0.086$) and urinary N:fecal N ratio ($P = 0.009$). A RAC × Lys interaction was observed for N digestibility ($P = 0.001$), excretion ($P = 0.001$), and retention ($P = 0.002$) and for fecal ($P = 0.001$) and urinary N ($P = 0.036$). By improving N and water utilization in finishing pigs, RAC-containing diets supplemented with sufficient Lys can reduce N excretion into the environment from swine facilities.

Key words: environment, nitrogen balance, ractopamine, swine, water

J. Anim. Sci. 2011. 89:2243–2256
doi:10.2527/jas.2010-3117

INTRODUCTION

Ractopamine hydrochloride (**RAC**; Paylean, Elanco Animal Health, Guelph, Ontario, Canada) is a β-adrenergic agonist. Inclusion of RAC in finishing swine diets increases ADG and G:F and improves carcass composition (NRC, 1994; Xiao et al., 1999; Patience et al., 2009). Ractopamine hydrochloride is a repartitioning agent, so energy is partitioned from lipid to protein accretion (Xiao et al., 1999). The improvements in growth and carcass quality are well noted in the literature, but research on other RAC benefits is limited.

[1]Program funding to the Prairie Swine Centre was provided by Saskatchewan Pork (Saskatoon, Saskatchewan, Canada), Alberta Pork (Edmonton, Alberta, Canada), Manitoba Pork Council (Winnipeg, Manitoba, Canada), and Saskatchewan Agriculture Development Fund (Regina, Saskatchewan, Canada). Project funding for this research was provided by Elanco Animal Health (Guelph, Ontario, Canada).

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Received April 23, 2010.
Accepted January 19, 2011.

Researchers have determined the ability of RAC to reduce nutrient excretion, but in these instances, greater amounts of RAC (18 to 20 mg of RAC/kg) were used (Carroll et al., 2001; DeCamp et al., 2001; Sutton et al., 2001). Currently, the Health Canada Veterinary Drug Directorate (North American Compendiums, 2007) approves 5 and 10 mg of RAC/kg in Canada, and the US Food and Drug Administration (2002) allows up to 10 mg/kg, although smaller amounts are often used in commercial practice. Further studies on the impact of smaller amounts of RAC on nutrient utilization are required.

Our hypothesis was that RAC would increase N utilization and retention, thereby reducing the excretion of N into the environment. These pigs would grow faster, which, in turn, would reduce feed and water requirements and decrease manure output per pig sold. The overall objective of this study was to define the impact of RAC on the efficiency of pork production, with a view to reducing the environmental footprint of pork production. The specific objectives were 1) to determine the effect of RAC on the efficiency of N utilization, 2) to evaluate the effect of RAC on animal performance, including improvements in carcass composition, and 3) to determine the impact of Lys inclusion on the response to RAC in pigs because feeding excess Lys could obviate the environmental benefits of RAC. The final objective was to compare the comparative slaughter and balance methods for determining N balance.

MATERIALS AND METHODS

All procedures used in this experiment were approved by the University of Saskatchewan Committee on Animal Care and Supply and adhered to principles established by the Canadian Council on Animal Care (1993).

This study consisted of a tissue accretion experiment and a metabolism experiment using 174 maternal-line barrows (Camborough Plus females × L42 sire, PIC Canada, Winnipeg, Manitoba, Canada), 120 and 54 for the growth and metabolism experiments, respectively, with an initial BW of 95 kg and a range of ±3 kg.

Treatments

Table 1 presents diet composition and analyzed nutrient content of the dietary treatments (as fed). Diets were based on wheat, barley, soybean meal, and canola oil. Celite (World Minerals, Santa Barbara, CA) was added as a source of insoluble ash, serving as a digestibility marker (Table 1). All diets were formulated to contain 3.30 Mcal of DE/kg and were formulated to meet or exceed the nutrient requirements of the finisher pig, with the exception of Lys (NRC, 1998). When Lys was increased, minimum ratios of AA to Lys were maintained so that as Lys increased, other limiting AA increased as well. Within each Lys amount, 3 different amounts of RAC (see below) were added at the expense of wheat. To ensure consistency of diet composition in both experiments, all experimental feed was prepared at the same time, pelleted, and bagged, and if not used immediately, stored at −20°C until required. Dietary treatments were arranged as a 3 × 3 factorial: 3 quantities of RAC (0, 5, and 10 mg/kg) and 3 standardized ileal digestible (**SID**) Lys:DE ratios (1.75, 2.25, and 2.75 g/Mcal).

Exp. 1: Tissue Accretion Experiment

Animal Selection, Identification, and Care. All barrows were individually weighed and sorted by BW, and the experiment commenced when the barrows reached a starting BW of 95 ± 3 kg. Forty barrows were selected for each of 3 replicates; the 10 barrows with the smallest range in BW were selected for each of the 4 blocks within replicate. Within each block, the pigs were randomly assigned to 1 of the 9 dietary treatments, and 1 pig in each block was assigned to the initial slaughter group (**ISG**). In total, this experiment was replicated 3 times, providing a total of 12 barrows per treatment (108 treatment pigs) plus 12 ISG pigs, or 120 barrows in total.

The experiment ended when the barrows reached their assigned final BW of either 108 ± 3 kg or 120 ± 3 kg; selection of slaughter BW within treatment and replicate was random. The ISG pigs were killed at the beginning of the experiment to provide an initial baseline carcass composition.

Barrows were housed in individual pens measuring 0.91 × 1.83 m (total 1.67 m^2). Each pen was equipped with a single-space dry feeder and a nipple drinker. Floors were made of slatted concrete and penning was made of polyvinyl chloride planking. The room temperature was set at 18°C, consistent with the thermoneutral zone for pigs of this size housed individually (Stanier et al., 1984). The lights were set on an automatic timer to turn on at 0700 h and off at 1900 h. Pigs received their dietary treatments, as well as water, for ad libitum intake. Weekly pig BW and feeder weigh backs were recorded to calculate growth performance.

Slaughter Procedure. When pigs reached their assigned slaughter BW, they were taken off test and weighed, and the feeders were removed from the pens. On the next day, pigs were reweighed and euthanized by captive bolt stunning, followed by exsanguination; all blood was collected into individual poly bags (6-mil Poly Bags, Uline, Waukegan, IL) and returned to the carcass. The carcass was split down the midline from the groin to the chest cavity, and the entire gastrointestinal tract was removed, emptied of digesta, and patted dry. The gallbladder and urinary bladder were also drained of contents. The emptied gastrointestinal tract was then returned to the carcass and an empty BW

Table 1. Ingredient composition of experimental diets fed to finishing pigs (%, as fed)[1]

	SID-Lys,[2] g/Mcal of DE		
Item	1.73	2.14	2.63
Ingredient, %			
Wheat	59.27	54.52	47.93
Barley	30.00	31.00	32.00
Soybean meal (46.5% CP)	6.40	10.00	15.50
Limestone	0.750	0.750	0.750
Dicalcium phosphate (18.5% P)	0.550	0.500	0.450
Salt	0.500	0.500	0.500
Mineral premix[3]	0.500	0.500	0.500
Vitamin premix[4]	0.500	0.500	0.500
L-Lys HCl	0.135	0.250	0.310
DL-Met	—	0.010	0.050
L-Thr	—	0.070	0.115
Canola oil	1.000	1.000	1.000
Celite[5]	0.400	0.400	0.400
Formulated analysis			
DE, Mcal/kg	3.30	3.30	3.30
Total Lys, %	0.65	0.84	1.03
SID-Lys, %	0.55	0.71	0.88
Analyzed, %			
DM	86.94	86.85	87.58
SID	0.80	0.80	0.80
N	2.28	2.46	2.72
Lys	0.67	0.83	1.02
Trp	0.17	0.19	0.21
TSAA	0.46	0.48	0.58
Thr	0.44	0.53	0.65
Crude fat	2.55	2.86	2.44

[1]Each diet contained 0, 5, or 10 mg/kg of ractopamine HCl (RAC; Paylean, Elanco Animal Health, Guelph, Ontario, Canada) at the expense of wheat for a total of 9 diets. Paylean provides 20 g of RAC/kg of premix.

[2]SID = standardized ileal digestible.

[3]Provided the following per kilogram of diet: Zn, 100 mg as zinc sulfate; Fe, 80 mg as ferrous sulfate; Cu, 50 mg as copper sulfate; Mn, 25 mg as manganous sulfate; I, 0.50 mg as calcium iodate; Se, 0.10 mg as sodium selenite.

[4]Provided the following per kilogram of diet: vitamin A, 8,250 IU; vitamin D, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; menadione, 4 mg; folacin, 2 mg; thiamine, 1 mg; D-biotin, 0.2 mg; vitamin B_{12}, 25 μg.

[5]Celite (World Minerals, Santa Barbara, CA) used as a source of insoluble ash.

(**EBW**) was recorded. The carcasses, including blood, were placed in poly bags, labeled, and frozen at −20°C for later grinding.

Carcasses were ground using an Autio GHP Grinder (model 801, Autio Company, Astoria, OR). The carcass was passed through a 12-mm die once and then a 6-mm die 3 times. A subsample was obtained on the final mix by taking random grab samples as the mince passed from the grinder. The grab samples were thoroughly mixed, and 3 subsamples were collected and frozen at −20°C. One subsample was freeze-dried in a model 25 LE Virtis freeze dryer (Virtis Co. Ltd., Gardiner, NY) for later analyses, and the 2 archive samples were stored at −20°C.

Exp. 2: Metabolism Experiment

Animal Selection, Identification, and Care. Animals required for the metabolism experiment were selected in a manner identical to that used for the tissue accretion experiment. However, the pigs were grouped within weekly outcome groups to provide 18 barrows, 2 per treatment, at each start-up. Three replicates were used, providing 6 pigs per treatment; therefore, 54 pigs were used in total.

Pigs were housed in metabolism pens (1.5 × 1.5 m) that allowed free movement similar to that of pigs housed in growth pens. The metabolism pen walls were made of polyvinyl chloride planking, with plastisol-coated woven expanded mesh floor (Tenderfoot, Tandem Products Inc., Minneapolis, MN). Plexiglass windows in each crate allowed for visual, but not physical, contact between pigs. These pens were equipped with a single-space dry feeder designed to minimize feed wastage. Pigs were provided feed twice daily, as much as they could consume within two 1-h meals. Feed was weighed before and after feeding periods to determine ADFI. Water was weighed and presented to the pigs in the feeder after the feeding periods. Thus, pigs had ad libitum access to water for 22 h out of each day.

Trays were placed underneath feeders to collect any spilled water to account for potential water wastage by the pigs. Before the next feeding, the remaining water was removed from the feeders and spillage trays and weighed to calculate daily water intake. This practice encouraged increased ADFI but also facilitated the most accurate recording of ad libitum water consumption.

Barrows remained in the crates for a period of 20 d; a 5 d acclimation period was used. The pigs were then placed on their assigned experimental diet (d 0) for a period of 15 d, with collection occurring on d 6 to 8 and on d 13 to 15, inclusive. The target average beginning BW for all pigs was 95 ± 3 kg. Average daily feed intake, average daily water intake, and G:F were recorded for the experimental period.

Sample Collection. The pens contained urine collection trays located under the floor to allow quantitative collection of urine through funnels into 4-L acid-washed jars. A screen was placed above the collection trays and glass wool was placed above the funnel to prevent contamination of urine with feces. Thirty milliliters of 6 *N* HCl was added to each jar daily to maintain a low pH and minimize N losses caused by volatilization. pH strips were used to randomly test the urine to ensure it remained below pH 2. Total urine collection was for a 72-h period in both sampling periods. Total urine produced was weighed, and a 10% aliquot was collected twice daily during the sampling period and stored at −20°C. The samples were pooled within pig and within collection period.

Feces were collected after every meal and throughout the day and early evening. Feces were collected directly when the pig voided and off the floor of the pen. Any feces that fell through the penning were collected off the screen. Although great care was taken to collect all feces, digestibility of nutrients was based on the marker method (Oresanya et al., 2008). Feces were pooled, weighed, and frozen at −20°C after each day of the collection period.

Sample Preparation

Feed samples were collected during the course of both the growth and metabolism experiments and pooled at the end of the experiment. The fecal samples were thawed and homogenized using a tilt-head mixer (model Accolade 400 series, Kitchen Aid, Mississauga, Ontario, Canada). Approximately 250 g of both carcass and fecal samples were lyophilized in a model 25 LE and model 25 ES Virtis freeze-dryer, respectively (Virtis Co. Ltd.). Carcass samples were blended in a Moulinex DPA2 800-watt food processor (Group SEB Canada, Scarborough, Ontario, Canada). Carcass, fecal, and feed samples were then ground through a 1-mm screen in a rotor mill (Model ZM1, Retsch, Newtown, PA). Urine samples, within pig and period, were thawed and mixed; two 170-mL urine samples were retained and refrozen for later analysis.

Chemical Analysis

Feed was assayed before being fed to experimental animals for a complete AA profile by the University of Missouri according to method 982.30 E (a,b,c; AOAC, 2006). A commercial laboratory (Norwest Labs, Lethbridge, Alberta, Canada) analyzed CP by the combustion method (method 990.30; AOAC, 1990) and moisture by the gravimetric method (method 935.29; AOAC, 1990). The RAC concentration was confirmed before the commencement of, and 4 times throughout the course of, the experiment to ensure that activity remained constant. The assay was conducted by HPLC (method B04372; University of Guelph, Guelph, Ontario, Canada).

Moisture contents of freeze-dried carcass samples, freeze-dried fecal samples, and feed samples were determined by drying at 135°C in an air-flow oven for 2 h (method 930.15; AOAC, 1990). Nitrogen was determined on carcass, feed, urine, and fecal samples by combustion (method 968.06; AOAC, 1990) using a Leco CP/N apparatus (Model FP-528, Leco Co., St. Joseph, MI); CP was calculated as N × 6.25, and EDTA was used daily as a calibration standard. Crude fat in feed and carcass samples was determined using a Soxhlet apparatus and with ethyl ether for feed and petroleum ether for carcass samples (method 920.39; AOAC, 1990). Ash content of feed and carcass samples was determined by incineration in a muffle furnace at 600°C for 12 h (method 942.05; AOAC, 1990). Acid insoluble ash, a digestibility marker, was determined for feed and fecal samples by gravimetry after treatment with 4 *N* HCl (modified method; McCarthy et al., 1974). All samples were analyzed in duplicate and repeated if CV values were greater than 1% for GE in feed and feces and greater than 3% for CP (feed, carcass, and fecal samples), moisture (feed, feces, and carcass), ash in feed, and fecal AIA. A CV value less than 5% was accepted for CP in urine, ash in carcass, AIA in feed, Ca and P in feed, and crude fat in carcass, and a CV value of less than 10% was used for crude fat in feed.

Statistical Analysis

The individual pig was considered the experimental unit in both the metabolism and tissue accretion experiments. All data were analyzed by the MIXED procedure (SAS Inst. Inc., Cary, NC), using the ANOVA model for all data, with the exception of growth performance data, which were analyzed by analysis of covariance, with initial BW as the covariate. Chemical analyses of samples were analyzed as a repeated measure with sampling period in days, and the Toeplitz model was determined as the appropriate covariance structure by SAS diagnostics. For the metabolism experiment, the main effects were RAC and Lys arranged as a 3 × 3 factorial, which allowed for determination of the main effects of RAC and Lys as well as their interaction. When RAC was significant, contrasts were performed

Table 2. Effect of ractopamine HCl (RAC), Lys, and slaughter BW on growth rate, feed intake, and feed conversion in finishing barrows: Exp. 1[1]

Item	Initial BW, kg	ADG, kg/d	ADFI,[2] kg/d	G:F, kg/kg
RAC, mg/kg				
0[3]	96.5	1.41	3.99	0.35
5[4]	95.9	1.41	3.93	0.36
10[4]	96.0	1.45	3.81	0.38
Lys, g/Mcal of DE				
1.73	95.9	1.40	3.95	0.35
2.14	96.3	1.38	3.90	0.35
2.63	96.3	1.49	3.87	0.39
SEM[5]	0.56	0.06	0.11	0.01
Slaughter BW, kg				
108	95.9	1.39	3.79	0.37
120	96.4	1.45	4.03	0.36
SEM[5]	0.52	0.05	0.10	0.01
		P-value		
Effect				
RAC	—	0.775	0.277	0.164
Lys	—	0.232	0.783	0.029
RAC × Lys	—	0.636	0.108	0.756
Slaughter BW	—	0.307	0.009	0.636

[1]Data expressed as least squares means. Data analyzed with initial BW as a covariate. The covariate was not significant for any measurement: ADG ($P = 0.559$), ADFI ($P = 0.666$), or G:F ($P = 0.741$).

[2]As fed.

[3]Average days on test was 19.

[4]Average days on test was 17.

[5]n = 36 for both RAC (Elanco Animal Health, Guelph, Ontario, Canada) and Lys; therefore, SEM values are presented in one row.

on controls compared with the average of the 5 and 10 mg of RAC/kg treatments, and the 5 mg of RAC/kg treatment was compared with the 10 mg of RAC/kg treatment. Data are reported as least squares means. In all cases, $P < 0.05$ was considered significant, and trends with *P*-values of $0.05 < P < 0.10$ were reported.

RESULTS

Experimental diets were assayed for AA content; total Lys was very close to formulated values, but the SID-Lys:DE ratios were found to be 1.73, 2.14, and 2.63 g/Mcal, compared with 1.75, 2.25, and 2.75. Consequently, the corrected ratios are presented hereafter. The estimated SID-Lys content, based on Lys assay values and assuming a SID coefficient of 85%, were 0.57, 0.71, and 0.87%, rather than the formulated values of 0.58, 0.75, and 0.85%, respectively.

Exp. 1: Tissue Accretion Experiment

Neither feed refusals nor health issues were observed during the tissue accretion experiment. Significant interactions ($P < 0.05$) are noted below and by a footnote in the appropriate table; otherwise, only main effects are presented.

Ractopamine had no effect on ADG, ADFI, or G:F (Table 2; $P > 0.10$). Lysine treatment had no effect on ADG or ADFI ($P > 0.10$). However, G:F increased with increased dietary Lys concentration ($P = 0.029$). Daily feed intake was greater in the 120-kg slaughter BW treatment ($P = 0.009$) compared with the 108-kg slaughter BW treatment. Slaughter BW did not affect ADG or G:F ($P > 0.10$).

Body composition as a percentage of EBW is presented in Table 3. Water (Table 3; $P = 0.007$) and CP ($P = 0.005$) contents were greater and lipid ($P = 0.019$) content was less in pigs fed RAC. Pigs fed RAC also tended to have greater EBW ($P = 0.050$). Ash content was similar among all treatments ($P > 0.10$). Empty BW CP was not increased ($P = 0.103$) and water content tended to increase ($P = 0.079$) with greater dietary Lys concentration, but ash, EBW, and lipid contents remained unchanged ($P > 0.10$). Fat ($P = 0.001$), CP, ash, and water contents and EBW ($P < 0.001$) were greater in the pigs slaughtered at 120 kg compared with those slaughtered at 108 kg.

An interaction was observed between dietary Lys concentration and slaughter BW on percentage of ash in the empty carcass (Table 3; $P = 0.022$; data not shown). Pigs slaughtered at 108 kg had small differences in percentage of ash among Lys treatments. Percentage of ash in the empty carcass declined in the pigs slaughtered at 120 kg as Lys increased. An interaction was also observed between RAC and the replicates on percentage of carcass water (Table 3; $P = 0.001$; data

Table 3. Effect of ractopamine HCl (RAC), Lys, and slaughter BW on body composition of finishing barrows: Exp. 1[1]

		Body composition, kg			
Item	Empty BW, kg	Protein	Lipid	Ash[2]	Water[3]
ISG barrows[4]					
Replicate 1	90.5	12.5	16.1	2.1	60.0
Replicate 2	89.6	13.0	13.4	2.3	60.9
Replicate 3	88.6	13.0	14.0	2.2	59.7
Treatment barrows					
RAC, mg/kg					
0	107.2	15.0	22.8	2.6	66.8
5	107.5	15.4	20.7	2.6	68.8
10	108.7	15.5	21.9	2.6	68.6
Lys, g/Mcal of DE					
1.73	107.4	15.2	22.5	2.6	67.4
2.14	107.9	15.3	22.0	2.6	67.9
2.63	108.0	15.5	21.0	2.5	68.9
SEM[5]	0.56	0.12	0.52	0.03	0.52
Slaughter BW, kg					
108	103.2	14.6	20.8	2.5	65.3
120	112.4	16.1	22.9	2.7	70.8
SEM[5]	0.49	0.10	0.42	0.02	0.44
	P-value				
Effect					
RAC	0.050	0.005	0.019	0.384	0.007
Lys	0.624	0.103	0.117	0.363	0.079
RAC × Lys	0.660	0.990	0.798	0.470	0.680
Slaughter BW	<0.001	<0.001	0.001	<0.001	<0.001

[1]Data expressed as least squares means.

[2]The interaction of Lys × slaughter BW was significant ($P = 0.022$).

[3]The interaction of RAC (Elanco Animal Health, Guelph, Ontario, Canada) × replicate was significant ($P = 0.001$).

[4]ISG = initial slaughter group. Data expressed as arithmetic means.

[5]n = 36 for both RAC and Lys; therefore, SEM values are presented in one row.

not shown). Pigs in replicate 1 had greater carcass water content with increased RAC amounts, but this was not observed in pigs in replicates 2 or 3.

Ractopamine did not increase protein deposition rates ($P = 0.111$), tended to increase water deposition rate ($P = 0.050$), and tended to reduce fat deposition rate (Table 4; $P = 0.055$). Protein deposition rate increased in response to greater Lys concentrations ($P = 0.027$). Dietary Lys concentration did not result in any differences in deposition rate of lipid or ash ($P > 0.10$), but tended to increase water deposition rate ($P = 0.066$). Pigs slaughtered at 120 kg of BW had increased deposition rates of protein ($P = 0.027$), fat ($P = 0.029$), and water ($P = 0.004$) compared with barrows slaughtered at 108 kg.

No increase in N retention was observed with greater RAC inclusion, whether expressed as the amount per day (Table 5; $P = 0.111$) or as a percentage of intake ($P = 0.109$). Lysine improved N intake ($P < 0.001$) and N retention, when expressed as grams per day ($P = 0.027$), but not when expressed as a percentage of intake ($P > 0.10$), and it tended to increase grams per day ($P = 0.083$) of N excretion, but not percentage of intake ($P > 0.10$). The pigs slaughtered at 120 kg retained more N than those slaughtered at 108 kg when expressed as grams per day ($P = 0.027$), and there was a no increase in N retention and excretion, expressed as a percentage of intake ($P = 0.108$).

Exp. 2: Metabolism Experiment

One pig (treatment with 5 mg of RAC/kg and 2.14 g of Lys/Mcal) was removed from the experiment because of a leg injury; there was no apparent relationship between the injury and the dietary treatment. No other health issues or feed refusals were observed.

Final BW ($P = 0.002$), ADG, ($P = 0.002$), and G:F ($P < 0.001$) increased as RAC concentration increased (Table 6); ADFI tended to increase as well ($P = 0.051$). Final BW, ADG ($P = 0.039$), and G:F ($P < 0.001$) increased and ADFI ($P = 0.027$) decreased with greater Lys inclusion.

Decreases in daily water intake ($P = 0.017$) and water excretion ($P = 0.033$; urine output and fecal moisture) were observed with increased RAC (Table 7). Ractopamine did not decrease apparent water retention (intake minus urine output minus fecal water output; $P = 0.102$). Increased Lys concentrations decreased daily fecal DM output ($P < 0.001$). Water intake, water excretion, and apparent water retention ($P > 0.10$) were

Table 4. Effect of ractopamine HCl (RAC), Lys, and slaughter BW on carcass nutrient deposition rates in finishing barrows: Exp. 1[1]

Item	Protein, g/d	Lipid, g/d	Ash, g/d	Water,[2] g/d
RAC, mg/kg				
0	162.1	619.8	26.3	466.3
5	185.4	461.6	25.2	608.7
10	189.2	542.3	27.1	572.5
Lys, g/Mcal of DE				
1.73	160.0	574.2	24.1	479.0
2.14	178.8	553.3	28.7	548.9
2.63	198.0	496.2	25.8	619.7
SEM[3]	10.77	49.68	2.18	45.80
Slaughter BW,[4] kg				
108	166.1	600.1	24.2	476.7
120	191.7	482.4	28.3	621.7
SEM[3]	9.20	42.22	1.78	38.97
		P-value		
Effect				
RAC	0.111	0.055	0.837	0.050
Lys	0.027	0.461	0.329	0.066
RAC × Lys	0.786	0.754	0.338	0.726
Slaughter BW	0.027	0.029	0.109	0.004

[1]Data expressed as least squares means

[2]The interaction of RAC (Elanco Animal Health, Guelph, Ontario, Canada) × replicate was significant ($P = 0.013$).

[3]n = 36 for both RAC and Lys; therefore, SEM values are presented in one row.

[4]The 108-kg group was calculated using the BW range of 95 to 108 kg, and the 120-kg group was calculated using the BW range of 95 to 120 kg.

Table 5. Effect of ractopamine HCl (RAC), Lys, and slaughter BW on N balance in finishing barrows: Exp. 1[1]

	N				
Item	Intake, g/d	Retention, g/d	Excretion,[2] g/d	Retention, % intake	Excretion, % intake
RAC, mg/kg					
0	91.0	25.9	65.0	28.8	71.2
5	92.4	29.7	62.7	32.3	67.7
10	89.5	30.3	59.3	34.1	66.0
Lys, g/Mcal of DE					
1.73	84.1	25.6	58.6	30.7	69.3
2.14	91.5	28.6	62.9	31.5	68.5
2.63	97.2	31.7	65.6	32.9	67.1
SEM[3]	1.94	1.72	2.51	1.98	1.98
Slaughter BW,[4] kg					
108	89.7	26.6	63.1	30.0	70.0
120	92.2	30.7	61.6	33.4	66.6
SEM[3]	1.65	1.47	2.17	1.70	1.70
			P-value		
Effect					
RAC	0.532	0.111	0.183	0.109	0.109
Lys	<0.001	0.027	0.083	0.675	0.675
RAC × Lys	0.227	0.786	0.479	0.933	0.933
Slaughter BW	0.224	0.027	0.573	0.108	0.108

[1]Data expressed as least squares means.

[2]N excretion calculated as the difference between N intake and N retention.

[3]n = 36 for both RAC (Elanco Animal Health, Guelph, Ontario, Canada) and Lys; therefore, SEM values are presented in one row.

[4]The 108-kg group was calculated using the BW range of 95 to 108 kg, and the 120-kg group was calculated using the BW range of 95 to 120 kg.

Table 6. Effect of ractopamine HCl (RAC) and Lys on final BW, growth rate, feed intake, feed efficiency, and water intake in finishing barrows: Exp. 2[1]

	BW, kg				
Item	Initial	Final	ADG,[2] kg/d	ADFI,[2,3] kg/d	G:F,[2,3] kg/kg
RAC, mg/kg					
0	93.8	110.2	1.09	3.17	0.34
5	93.8	112.9	1.27	3.23	0.39
10	94.1	112.7	1.25	3.03	0.41
SEM	0.65	0.54	0.04	0.06	0.01
Lys, g/Mcal of DE					
1.73	93.5	110.9	1.13	3.26	0.35
2.14	94.2	112.9	1.27	3.14	0.40
2.63	94.0	112.0	1.21	3.03	0.40
SEM	0.65	0.54	0.04	0.06	0.01
			P-value		
Effect					
RAC	—	0.002	0.002	0.051	<0.001
Lys	—	0.039	0.039	0.027	<0.001
RAC × Lys	—	0.654	0.650	0.918	0.579

[1]Data expressed as least squares means. Data analyzed with initial BW as a covariate. The covariate was significant for ADFI ($P < 0.001$), feed conversion ($P = 0.034$), and final BW ($P < 0.001$), but not for ADG ($P = 0.318$). Ractopamine supplied by Elanco Animal Health, Guelph, Ontario, Canada.

[2]Calculated based on 15-d experimental period.

[3]As-fed basis.

Table 7. Effect of ractopamine HCl (RAC) and Lys on feed and water intake, fecal and urine water output, total water excretion, and apparent water retention in finishing barrows: Exp. 2[1]

Item	Water intake,[2] L/d	Fecal output,[3] kg/d	Water excretion,[4] L/d	Apparent water retention,[5] L/d
RAC, mg/kg				
0	8.3	0.4	3.9	4.4
5	7.9	0.5	3.6	4.4
10	7.3	0.4	3.2	4.1
SEM	0.25	0.01	0.18	0.12
Lys, g/Mcal of DE				
1.73	7.9	0.5	3.6	4.4
2.14	7.5	0.5	3.3	4.2
2.63	8.1	0.4	3.7	4.4
SEM	0.25	0.01	0.18	0.12
Sample period, d				
d 6 to 8	7.7	0.4	3.4	4.3
d 13 to 15	8.0	0.5	3.7	4.3
SEM	0.15	0.01	0.12	0.09
			P-value	
Effect				
RAC	0.017	0.018	0.033	0.102
Lys	0.186	<0.001	0.276	0.337
RAC × Lys	0.994	0.060	0.769	0.125
Sample period	0.051	0.025	0.014	0.828

[1]Data expressed as least squares means. Data analyzed as repeated measures across sampling periods. Ractopamine supplied by Elanco Animal Health, Guelph, Ontario, Canada.

[2]Water intake included water consumption and diet moisture.

[3]DM basis.

[4]Water excretion is the sum of fecal water output and urine output.

[5]Apparent water retention calculated as the difference between water intake and urine and fecal water excretion. Water lost because of respiration was not accounted for.

similar among Lys treatments. Fecal DM output ($P = 0.025$) and water excretion ($P = 0.014$) were greater during the d 13 to 15 sampling period than the d 6 to 8 period. The pigs in the d 13 to 15 sampling period tended to have greater water intake ($P = 0.051$), but apparent water retention was not different across the sampling period ($P > 0.10$).

Nitrogen digestibility ($P = 0.008$) and N intake ($P = 0.003$), urinary N excretion ($P = 0.001$), fecal N excretion ($P = 0.003$), and total N excretion ($P = 0.004$) decreased and N retention ($P = 0.003$) increased as dietary RAC increased, when expressed as grams per day (Table 8). Nitrogen digestibility ($P < 0.001$) and N intake ($P < 0.001$), urinary N excretion ($P = 0.002$), total N excretion ($P = 0.010$), and N retention ($P = 0.001$) increased with greater dietary Lys concentration (Table 8), but fecal N excretion was unaffected, when expressed as grams per day ($P > 0.10$). From d 13 to 15, the barrows had greater N intake ($P < 0.001$), urinary N excretion ($P = 0.002$), fecal N excretion ($P = 0.021$), total N excretion ($P = 0.001$), and N retention ($P = 0.015$) compared with d 6 to 8, when expressed as grams per day. Nitrogen digestibility was unaffected by sampling period ($P > 0.10$). A RAC × Lys interaction occurred for N retention (g/d; Figure 1; $P = 0.002$) and N digestibility (Figure 2; $P = 0.001$). The barrows fed 2.14 or 2.63 g of Lys/Mcal had improved N retention (g/d) when fed 5 mg of RAC/kg compared with the control pigs; at 1.75 g of Lys/Mcal, pigs fed 0 and 10 mg of RAC/kg had improved N retention compared with pigs receiving 5 mg of RAC/kg. Nitrogen digestibility was the greatest in control pigs fed 1.73 and 2.14 g of Lys/Mcal; however, pigs fed 2.63 g of Lys/Mcal had improved N digestibility with RAC inclusion.

Urinary N ($P < 0.001$) and N excretion ($P = 0.003$) decreased, whereas N retention ($P = 0.003$) and fecal N ($P = 0.008$) increased, when expressed as percentage of N intake, and the urinary N:fecal N ratio decreased ($P < 0.001$) with greater RAC inclusion (Table 8). Percentage of fecal N ($P < 0.001$) decreased and percentage of N excretion tended to decrease ($P = 0.086$) with greater Lys concentrations. Percentage of urinary N ($P = 0.069$) tended to be greatest for barrows fed the greatest Lys and percentage of N retention ($P = 0.086$) tended to be greatest for barrows fed the midlevel of Lys. The sample period had no effect on N balance ($P > 0.10$). Expressed as percentage of N intake, fecal and urinary N excretion, N excretion, and N retention all had significant RAC × Lys interactions. Ractopamine increased fecal N in pigs fed 1.73 and 2.14 g of Lys/Mcal, but it decreased in pigs fed 2.63 g/Mcal. Urinary N decreased in pigs fed RAC supplemented with greater Lys. However, at the least amount of Lys fed, pigs fed 10 mg of RAC/kg had decreased urinary N. At the least amount of Lys fed, pigs receiving 5 mg of RAC/kg had the greatest N excretion, but at 2.14 and 2.63 g/Mcal, the control pigs had the greatest N excretion. Nitrogen retention was greater in pigs fed RAC at all Lys amounts, except in pigs fed 5 mg of RAC/kg and receiving the least amount of Lys, which had decreased N retention.

DISCUSSION

The absence of a RAC × Lys interaction in the tissue accretion experiment is puzzling. The least amount of Lys fed was deficient for pigs of this age when expressed as a percentage of the diet (NRC, 1998), but in the tissue accretion experiment, no response to Lys was observed. This may be due to the excellent feed intake, approaching 4.0 kg/d, which resulted in a SID-Lys intake of more than 22 g/d, even on the low-Lys diet. It was expected that individually housed pigs would have greater feed intake than group-housed pigs (Nielsen et al., 1996); however, even in the low-Lys diet, Lys was greater than the requirement for even the most productive of finishing pigs, according to the NRC (1998). Although the possibility of an AA deficiency exists, the totality of the data does not support this conclusion. First, if Lys was limiting the response to RAC, then there should have been an interaction between RAC and Lys, and one was not observed for any growth variable. Second, in the growth study (Exp. 1), daily SID-Lys intake on the diet with the greatest amount of Lys was approximately 34 g/d. Assuming the maintenance requirement for Lys is 36 mg/kg$^{0.75}$ (NRC, 1998) or 1.2 g/d, 32.8 g of SID-Lys is available per day for protein accretion. The pigs fed RAC were accreting as much as 190 g of protein/d, which is equivalent to approximately 13 g of Lys/d. With the determined SID-Lys intake available for Lys accretion of 32.8 g/d, an efficiency of utilization of dietary Lys for protein accretion of only 40% would be necessary to meet the need of the pig for dietary Lys. It is highly unlikely that the efficiency is that low (Möhn et al., 2000; Heger et al., 2002). Third, protein gain in the pigs fed RAC was approximately 16% more than that of the control pigs, which is in the normal range of response to RAC. Fourth, and perhaps the weakest but still relevant point, Elanco recommends 0.90 g/kg of SID-Lys for finishing pigs fed 5 g/kg of RAC. We were only slightly below this amount, but again, ADFI was excellent in the experimental pigs. We readily admit that our first thoughts, when the experiment concluded, was that Lys was limiting, but for the reasons stated above, we concluded that this does not explain the results.

Because other AA were formulated according to a ratio to Lys, all AA intakes increased as Lys intake increased. Consideration was given to a secondary AA being deficient and preventing the response to Lys, but actual intakes of each AA disproved this possibility (NRC, 1998). The composition of BW gain, as opposed to total BW gain, tells a different story. Pigs increased protein deposition rates as Lys increased, and they tended to do so as RAC increased. This underscores the importance of investigating the composition of BW

Table 8. Effect of ractopamine HCl (RAC) and Lys concentration on N balance in finishing pigs: Exp. 2[1]

Item	N intake, g/d	N digestibility, %	Urinary N excretion, g/d	Fecal N excretion, g/d	Total N excretion, g/d	N retention, g/d	Urine N:fecal N, % of N intake	Urinary N excretion, % of N intake	Fecal N excretion, % of N intake	Total N excretion, % of N intake	N retention, % of N intake
RAC, mg/kg											
0	80.5	84.4	28.5	12.6	41.1	39.4	2.3	35.1	15.6	50.7	49.3
5	84.1	83.2	25.5	14.1	39.6	44.5	1.8	30.2	16.8	47.0	53.0
10	77.0	83.8	23.3	12.6	35.9	41.1	1.9	29.8	16.2	46.0	54.0
SEM	1.43	0.26	0.95	0.37	1.12	1.03	0.07	1.01	0.26	0.99	0.97
Lys, g/Mcal of DE											
1.73	76.0	83.0	24.6	13.0	37.6	38.4	1.9	32.2	17.0	49.2	50.8
2.14	80.4	83.7	24.1	13.2	37.3	43.0	1.9	29.9	16.3	46.2	53.8
2.63	85.2	84.8	28.6	13.1	41.7	43.6	2.2	33.1	15.2	48.3	51.7
SEM	1.44	0.26	0.96	0.37	1.13	1.07	0.07	1.02	0.26	1.00	1.00
Sample period, d											
d 6 to 8	77.1	83.7	24.1	12.7	36.8	40.3	1.9	30.9	16.3	47.2	52.8
d 13 to 15	89.0	83.9	27.4	13.5	41.0	43.0	2.1	32.5	16.1	48.6	51.4
SEM	1.10	0.20	0.74	0.27	0.84	0.79	0.06	0.79	0.22	0.75	0.75
	P-value										
Effect											
RAC	0.003	0.008	0.001	0.003	0.004	0.003	<0.001	<0.001	0.008	0.003	0.003
Lys	<0.001	<0.001	0.002	0.907	0.010	0.001	0.009	0.069	<0.001	0.086	0.086
RAC × Lys	0.441	0.001	0.137	0.080	0.072	0.002	0.466	0.036	0.001	0.002	0.002
Sample period	<0.001	0.412	0.002	0.021	0.001	0.015	0.139	0.129	0.412	0.154	0.155

[1]Data expressed as least squares means. Data analyzed as repeated measures across sampling periods.

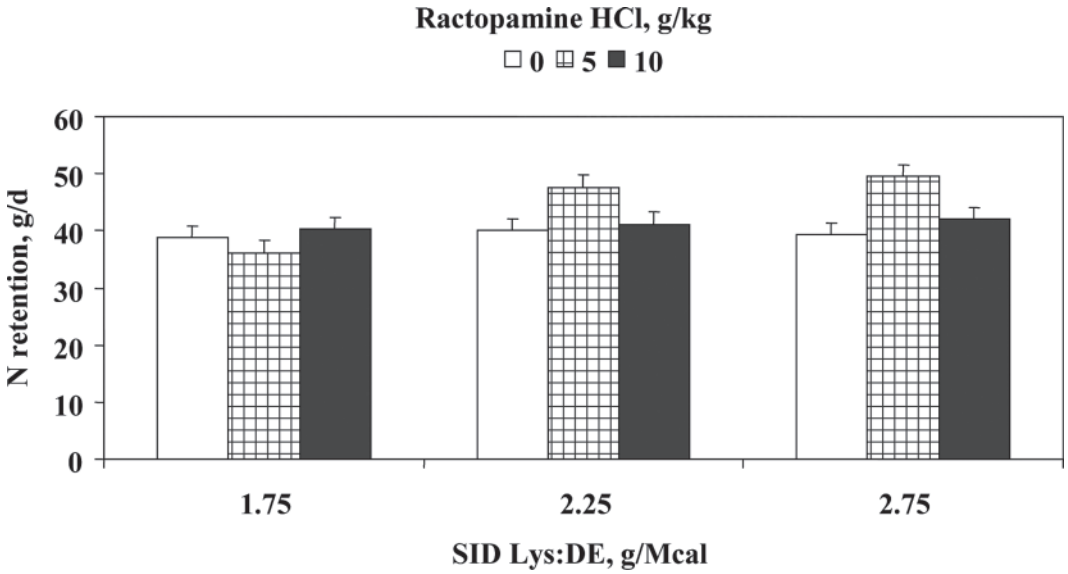

Figure 1. Interaction between dietary standardized ileal digestible (SID)-Lys and ractopamine HCl (Elanco Animal Health, Guelph, Ontario, Canada) on N retention ($P = 0.002$). Error bars represent the SEM.

gain in pigs, which may provide a different interpretation of results from those observed with only whole-body data (Oresanya et al., 2008).

Consistent with the excellent feed intake, the pigs had an impressive protein deposition rate; for example, the pigs receiving the greatest amount of Lys were depositing 198 g of protein/d, similar to that reported by Webster et al. (2007), who reported pigs depositing 191 g of protein/d.

What is most puzzling about this study is the almost complete absence of a RAC × Lys interaction in growth variables in both the growth and metabolism experiments. This was unexpected and is very difficult to explain. It is very well known that pigs fed RAC have a greater requirement for Lys than untreated pigs (Xiao et al., 1999; Webster et al., 2007), yet the absence of an interaction between RAC and Lys suggests that the smallest amount of Lys fed was adequate for pigs fed 10 mg of RAC/kg. The interaction was observed in the metabolism experiment, but not the tissue accretion experiment, when considering the various components of N metabolism. No explanation is available for the unexpected outcome.

Ractopamine had no effect on pig performance in the tissue accretion experiment, but in the metabolism experiment, RAC increased ADG and G:F. The dissimilarity between the experiments may have been due to feed intake differences. The ADFI averaged 3.1 kg/d in the metabolism experiment and 3.9 kg/d in the tissue accretion experiment. As a result, daily intake of Lys was also different. In a meta-analysis of 23 published reports, Apple et al. (2007) concluded that RAC supplemented at 5, 10, or 20 mg/kg significantly improved ADG and G:F in finishing pigs. Recently, Patience et

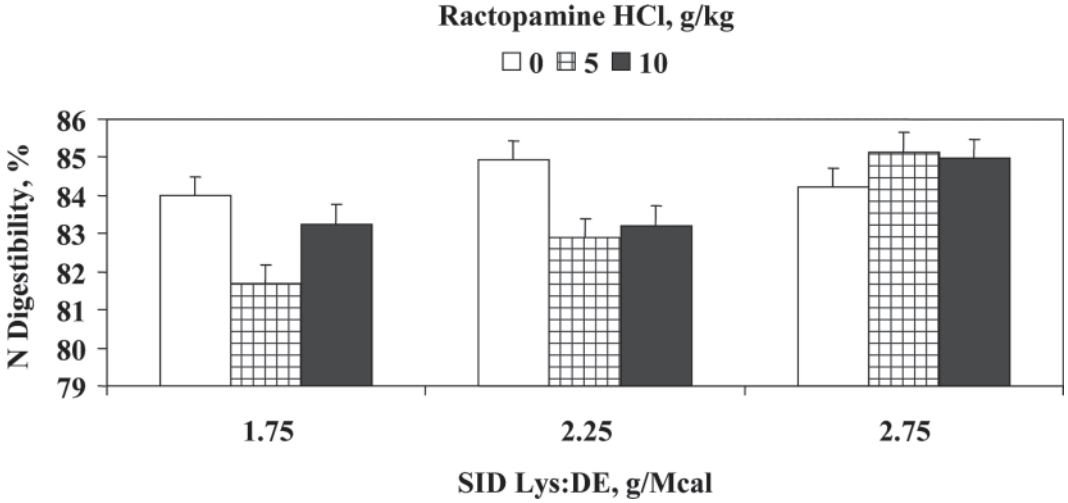

Figure 2. Interaction between dietary standardized ileal digestible (SID)-Lys and ractopamine HCl (Elanco Animal Health, Guelph, Ontario, Canada) on N digestibility ($P = 0.001$). Error bars represent the SEM.

al. (2009) found ADG and G:F increases of 13% compared with those of control pigs with supplementation of only 5 mg of RAC/kg. In comparison, Brumm et al. (2004), Carr et al. (2005), and Mimbs et al. (2005) all reported no effect of 10 mg of RAC/kg on ADG when compared with ADG of control pigs; G:F however, was improved. In addition, with inclusion of 10 mg of RAC/kg, ADFI decreased while ADG remained unchanged. Conversely, See et al. (2005) reported no increase in G:F at 5 or 10 mg of RAC/kg, but ADG improved with increasing amounts of dietary RAC even though ADFI did not differ among treatments. Thus, the growth performance of pigs does not always respond in a predictable way to RAC, as we report herein.

There is an inverse relationship between lipid and water content in swine tissue. Therefore, it would be assumed that a leaner pig would require more water to sustain the increase in protein deposition (Apple et al., 2007). In the tissue accretion experiment, it was no surprise that the addition of either 5 or 10 mg of RAC/kg to the diet increased both the protein and water contents of the carcasses. Similar results using 20 mg of RAC/kg were reported by Uttaro et al. (1993) and Xiao et al. (1999) in the LM and by Dunshea et al. (1993, 1998) in the whole carcass (EBW). The decreases in water intake and urine output in the presence of RAC were therefore a puzzle, given this close association between protein accretion and water accretion.

However, it is also well known that in mammals, urine is the key vehicle for N excretion (Smith et al., 2004), and the results obtained for N balance in the metabolism experiment agree with this. Total N excretion decreased by 5.2 g/d (4.7%) and urinary N decreased by as much as 5.4% when pigs were fed 10 mg of RAC/kg, compared with the control group. Thus, it would appear that the quantity of water excreted by the pig is driven more by the need to remove excess N from the body than by the need to retain more water in the lean tissue. The reduction in total N excretion and urinary N excretion shows that RAC can reduce the N load in manure; this reduces the environmental impact of pork production by lessening the amount of N applied to agricultural land.

In the tissue accretion experiment, a 108-kg slaughter BW was used along with a 120-kg slaughter BW because carcass differences may occur with prolonged RAC use resulting from desensitization of the β-adrenergic receptors (NRC, 1994; Bell et al., 1998). Therefore, a response to RAC may initially increase and then decline as the test period progresses, so an estimation of protein and lipid deposition at an intermediate BW was deemed necessary. This is particularly important in determining the efficiency of nutrient utilization as influenced by RAC treatment. The pigs slaughtered at 120 kg had greater CP and water deposition rates than the pigs slaughtered at 108 kg. These results indicate that desensitization to RAC did not occur. The desensitization may not have occurred in these pigs because the time required to reach 120 kg was only an average of 19 d for control animals and an average of 17 d for pigs treated with RAC. Armstrong et al. (2005) found that desensitization to RAC occurred when pigs were fed at a constant amount for 35 d and the treatment was initiated at 78.5 kg. The pigs in that tissue accretion experiment were not supplemented with RAC until 95 ± 3 kg and were fed no longer than 25 d (Armstrong et al., 2005).

Nitrogen balance in the tissue accretion experiment differed from that obtained in the metabolism experiment. In the tissue accretion experiment, N retention averaged 31.7% of intake, whereas in the metabolism experiment, it averaged 51.8%. The determination of N retention by comparative slaughter has typically shown to be closer to the true N retention of the animal when compared with N balance studies; however, when gaseous N losses are measured, the 2 methods are equivalent (Quiniou et al., 1995). The N excretion values obtained in the metabolism study appear to be underestimated, which may be due in part to volatilization of ammonia N during urine collection. The urine collection trays used herein have a large surface area (0.91 × 1.83 m); this could result in larger quantities of ammonia being lost before the urine reached the acidified collection containers. In addition, Quiniou et al. (1995) reported that N losses can occur when feces are dried, again resulting in an overestimation of N retention. However, the N retention values reported herein from the metabolism study are greater than those reported by at least some other authors (Fabian et al., 2004; Lynch et al., 2007); these values agree more with the N retention values obtained in the comparative slaughter study. Fabian et al. (2004) obtained values between 33 to 35% of N intake and Lynch et al. (2007) obtained values between 32 to 47% of N intake. On the other hand, O'Connell et al. (2006) obtained N retention values between 53 to 55% of intake, which agrees with the results of our metabolism study. Aarnink and Verstegen (2007) suggested that the N retention of finisher pigs is approximately 30%. It is generally accepted that metabolism experiments will overestimate N retention because of volatilization losses from urine and feces and because comparative slaughter experiments will underestimate N retention owing to difficulties in measuring N lost in skin, scale, and sweat (Fuller and Garlick, 1994). The results of this study would appear to support this conclusion.

In summary, supplementation with RAC in finishing swine diets improved the N utilization of barrows. Total N excretion was reduced by 5.2 g/d in pigs fed 10 mg of RAC/kg when compared with control pigs. The reduction in total N excretion was due to RAC reducing urinary N excretion, as well as improving N retention. It is interesting that the pigs fed 10 mg of RAC/kg consumed approximately 1 L/d less water and excreted 0.7 L/d less water than control pigs. Dietary RAC improved growth performance in the metabolism experiment, but not in the tissue accretion experiment. However, pigs in the tissue accretion experiment, regardless of treat-

ment, had excellent BW gain efficiencies. Dietary RAC inclusion of 10 mg of RAC/kg increased carcass protein by 0.5% and carcass water by 1.8% and decreased lipid content by 0.9% when compared with those of control pigs. Daily deposition rates of lipid tended to decrease, whereas protein deposition rates improved numerically. Previous research has shown that the amount of Lys inclusion influences growth performance or carcass characteristics, but this did not occur in this experiment, which was unexpected. When dietary Lys increased, pigs fed RAC did not demonstrate improved growth performance or carcass characteristics. Nitrogen retention was greater than in previously published reports, perhaps because of volatilization of urinary N as ammonia. This may have caused differences in N balance results between the growth and metabolism experiments. Future studies using the N balance method must ensure that volatilization losses are minimized.

In conclusion, RAC reduces the environmental footprint associated with producing pork. Results from these experiments indicate that supplementing either 5 or 10 mg of RAC/kg in finishing swine diets improves N utilization. A decrease in urinary N excretion from 35.1 to 30.2% and an improvement in N retention from 49.3 to 53.0% in control pigs and pigs fed 5 mg of RAC/kg, respectively, can reduce the presence of excess N in manure. Ractopamine also improved protein deposition rates to 185.4 g/d in the pigs fed 5 mg of RAC/kg, compared with 162.1 g/d in control pigs, whereas lipid deposition rates decreased from 619.8 g/d in control pigs to 461.6 g/d in pigs fed 5 mg of RAC/kg. Supplementing RAC produced a leaner carcass with improved nutrient utilization. In addition, RAC reduced water intake by 1 L/d, and water excretion was reduced by 0.7 L/d with feeding 10 mg of RAC/kg, which can decrease requirements for water consumption in finishing hogs.

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